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(71) Applicant: KONINKLIJKE PHILIPS ELECTRONICS N.V. [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(71) Applicant *(for SE only)*: PHILIPS AB [SE/SE]; Kottbygatan 7, Kista, S-164 85 Stockholm (SE).

(72) Inventors: SPRUIT, Johannes, H., M.; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL). DUCHATEAU, Johan, P., W., B.; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).

(74) Agent: VISSER, Derk; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).

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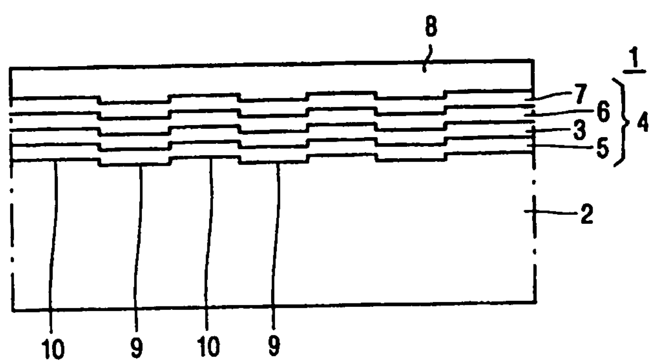

(57) Abstract

An optical recording medium is described having a grooved recording layer. The structure of unwritten tracks must enable a scanning device to derive a radial tracking error signal according to the push-pull method. The structure of the written tracks must enable the scanning device to derive a radial tracking error signal according to the high-frequency phase-detection method. To this end the width and depth of the groove are in the range from 0.3 to 0.6 times the wavelength over the numerical aperture of the radiation beam used for scanning the recording medium, and from 1/24 to 1/7 times the wavelength over the refractive index, respectively. The phase difference between the radiation beam reflected from a region on track in between written marks and from a mark is in the range from 0.4 to 2.0 radians.

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Optical recording medium.

The invention relates to an optical recording medium for writing and reading information by means of a radiation beam having a predetermined wavelength and a predetermined numerical aperture, comprising a recording layer, the recording layer being changed from a first to a second state upon irradiation by a radiation beam, the recorded information being represented by written marks in the second state in a region in the first state, the marks being arranged in tracks comprising a guide groove having a width and a depth, a first optical phase difference existing on reflection from a region on track in the first state and from a region on track in the second state, the first optical phase difference enhancing an optical phase difference between a region in between tracks in the first state and a region on track in the first state.

Information may be stored in such a recording medium by a scanning device having an optical head. The head focuses a radiation beam onto the information layer in the medium and follows an unwritten track by means of tracking information derived from the groove in the track. When the medium is disc-shaped, the grooves are circular or spiral and the tracking information is in the form of a radial tracking error signal. When a relatively high power radiation beam is modulated by a signal representing the information to be written, the information is written in the track in the form of optically detectable marks. During reading the radiation beam has a relatively low power, which, on reflection from the information layer, is modulated by the marks. The tracking information may be derived during reading from the grooves or from the written information.

An optical recording medium according to the preamble is known from the Japanese patent application JP-A 5174380. This medium comprises a stack of optical thin layers in which the recording layer is embedded. The thickness of a transparent layer of the stack adjacent the recording layer is tuned such that the first optical phase difference between unwritten and written regions of a track increases a second optical phase difference between a region in between tracks in the first state and a region on track also in the first state. This relation between the phase differences increases the information signal derived from the scanned marks. A disadvantage of the known recording medium is that the tracks cannot properly be followed by a scanning device using the so-called push-pull method and phase

detection method for deriving a tracking signal from marks written in the information layer. The push-pull method and phase detection method of deriving tracking information is known from inter alia United States patent no. 4 057 833 and 4 785 441, respectively.

It is an object of the invention to provide an optical recording medium from which tracking information can be derived from the written marks according to the push-pull method and also from the written information.

This object is achieved when the recording medium according to the preamble is characterized in that the width of the guide groove is in the range from 0.3 to 0.6 times the wavelength over the numerical aperture, the depth of the guide groove is in the range from 1/24 to 1/7 times the wavelength over a refractive index met by the radiation beam,, and the first optical phase difference is in the range from 0.4 to 2.0 radian. The combination of the particular values of the groove width and the phase difference provides both a high-quality push-pull signal and phase detection signal and a high-quality information signal from the written marks. The phase difference enhances both the information signal and the push-pull signal. The minimum groove depth provides that a scanning device will be able to derive a high-quality push-pull signal from the grooves. Grooves deeper than the maximum groove depth reduce the quality of the phase detection signal. Moreover, the phase detection signal from deeper grooves becomes strongly dependent on the defocus of the radiation beam. The depth of the groove is given as the mechanical depth. The refractive index met by the radiation beam is the index of the material in between the grooves. The material is that of a transparent substrate or of a protective layer if the radiation beam is incident on the recording layer through the substrate or through the protective layer, respectively. The width of the grooves is preferably larger than the width of the marks designed to be written in the recording layer.

The tracking signal formed by the phase-detection method is generally affected by the axial position of the focal point of the radiation beam with respect to the position of the recording layer. When the radiation beam is not in focus on the recording layer, the amplitude of the tracking signal may decrease significantly and even change sign. This effect is already mitigated when the first phase difference lies within the range from 0.4 to 2.0 radians. A further reduction of the effect will be achieved when the width and depth of the guide groove comply with

$$8.33\ NA\ D / n + 121\ NA / \lambda - 400\ NA\ \Phi / \lambda < W,$$

where NA is the numerical aperture, λ the wavelength in nanometres, Φ the first optical phase difference in radians, n the refractive index, D the depth in units of λ / n and W the width in units of λ / NA.

The first optical phase difference is preferable in the range from 0.4 to 1.1 radian. A medium having a phase difference smaller than this value will show an asymmetric tracking signal as derived by the phase-detection method. The asymmetry shows up as different amplitudes of the tracking signal when the radiation beam is focussed below and above the recording layer. A possible measure of the asymmetry is (x-y)/(2z), where x is the maximum value of the phase-detection tracking error signal when the radiation beam is focussed 1 µm above the information plane, y the maximum value of the phase-detection tracking error signal when the radiation beam is focussed 1 µm below the information plane and z the maximum value of the phase-detection tracking error signal when the radiation beam is focussed on the information plane.

A further improvement of the phase-detection tracking signal can be achieved when a ratio of an intensity reflection of a region on track in the second state and of a region on track in the first state is larger than 0.15. Such a medium is called a dark-writing medium. A so-called white-writing medium has preferably a ratio of the intensity reflection of a region on track in the first state and of a region on track in the second state larger than 0.15. The symmetry of the tracking signal as derived by the phase-detection method is improved when the ratio lies within the range from 0.3 to 0.5 for both dark- and white-writing media.

The intensity reflection of a region on track in the first state is preferably larger than 0.15 for a dark-writing medium, in order to be able to derive a good information signal from the radiation reflected from the information layer. For a white-writing medium, the intensity reflection of a region on track in the second state is preferably larger than 0.15.

The groove in the information layer may be used for storing information such as addresses used in accessing the information. Such information may be stored in the form of a wobble in the depth or position of the groove. The depth of the groove is then preferably in the range from 1/12 to 1/7 times the wavelength of the radiation beam over the refractive index.

The optical phase difference of the medium may be realized by embedding the recording layer in a stack of optical thin layers and tuning the thicknesses of the layers. The design of the stack is facilitated when the material of the recording layer in the first state has an imaginary part of the refractive index larger than 3.4.

The material of the recording layer is preferably of a phase-change type. The writing speed can be relatively high when amorphous marks are written in a crystalline layer. The first state is then a crystalline state and the second state an amorphous state.

In view of the not-pre-published international patent application no. IB97/01470, record carriers having the combination of a groove depth, groove width, track period of: 40 nm, 500 nm, 900 nm, and 55 nm, 400 nm, 900 nm, and 51 nm, 500 nm, 870 nm, all having a refractive index n of 1.58 and a design wavelength of 670 nm are disclaimed.

These and other aspects of the invention will be apparent from and be elucidated with reference to the embodiments described hereinafter

In the drawings

Figure 1 shows a cross-section of a recording medium according to the invention;

Figure 2 shows a plan view of the recording layer of the medium;

Figure 3 shows a scanning device for scanning media according to the invention;

Figure 4A shows the circuit of the device for forming a push-pull radial tracking error signal; and

Figure 4B shows the circuit of the device for forming a DTD radial tracking error signal.

Figure 1 shows an information recording medium 1 according to the invention designed for writing and reading information by means of a focussed radiation beam having a design wavelength and numerical aperture. Medium 1 comprises a transparent substrate 2 and a recording layer 3. The recording layer may be scanned by a radiation beam incident on the recording layer through substrate 2. Recording layer 3 is embedded in a stack 4 of optical thin layers arranged on substrate 2. The stack comprises from the substrate side a transparent interference layer 5, recording layer 3, a further interference layer 6, and a reflective layer 7. Stack 4 is shielded from environmental influences by a protective layer 8.

Substrate 2 comprises a groove pattern on the side on which stack 4 is arranged. For a disc-shaped medium the groove pattern has circular or spiral grooves. The part of the groove pattern in the Figure forming a depression in the substrate when viewed from the side of the stack is called a groove 9. The part of the pattern in the Figure forming a raised part

from the same point of view is called a land 10. The width of the groove is determined at the top of the groove, i.e. at the land level. The thickness of the layers in stack 4 is so small that the pattern on the substrate 2 is also present in recording layer 3. The following examples are designed for writing in the groove 9 of the recording medium. When, on the other hand, the recording medium is designed for recording on the part 10, the optimum parameter values for the depth and width of the grooves according to the invention apply likewise, but the part of the pattern 9 in the Figure should be labelled as land and the part 10 as groove.

EXAMPLE I

The substrate of the recording medium is made of polycarbonate (PC) having a refractive index of 1.58 at the design wavelength of 670 nm and numerical aperture of 0.60. Interference layer 5 is a 90 nm thick layer of 80% ZnS and 20% SiO_2 having a refractive index of 2.13. Recording layer 3 is a 30 nm thick layer of a $GeSb_2Te_4$ phase-change material having a refractive index of 4.26 - i 1.69 when in the amorphous state and 4.44 - i 3.08 when in the crystalline state. Interference layer 6 is a 30 nm thick layer of the same material as interference layer 5. Reflective layer 7 is a 100 nm thick layer of an aluminium alloy having a refractive index of 1.98 - i 7.81. The mechanical depth d of grooves 9 is 55 nm, the width w of the grooves is 450 nm and the pitch of the grooves, being the track pitch is 740 nm. The dimensionless groove depth D is equal to $d\,n / \lambda = 0.130$, n being the refractive index of the substrate, the dimensionless groove width W is equal to $w\,NA / \lambda = 0.403$.

Figure 2 shows part of recording layer 3 having grooves 9 and lands 10. The information is written in the grooves. Recording layer 3 is initially in the crystalline state. During writing amorphous regions 11, called marks, are made in the recording layer. The length and position of the marks represent the information recorded in the medium. The intensity reflection of stack 4 in a region of the recording layer in the amorphous state is equal to 0.07. The intensity reflection of stack 4 in a region in the crystalline state is equal to 0.18. The ratio of the amorphous reflection over the crystalline reflection is thus 0.39. Both intensity reflections have been measured by means of a focussed radiation beam in regions without grooves.

Radiation reflected from a region on track and in the crystalline state, indicated by 'a' in Figure 2, is advanced in phase by 1.64 radian compared to radiation reflected from a region 'b' in between tracks and also in the crystalline state. Radiation reflected from a region on track and in the amorphous state, indicated by 'c' in Figure 2, is advanced in phase by 0.6

radian compared to radiation reflected from a region on track and in the crystalline state. Hence, the phase difference between the land and groove is enhanced by the phase difference between mark and regions in between marks. Put differently, the effective depth of the groove is enhanced at the location of the marks.

The push-pull tracking error signal has a measured maximum value of more than 95% of the value obtained for a medium having a groove depth optimized for a maximum push-pull signal. The phase-detection tracking error signal of the so-called DTD-2 type has a maximum value of 0.69 clock periods at a 0.1 μm radial tracking deviation of the focal spot, as measured by a scanning device described below. The value of the tracking error signal is a time difference normalized on the channel clock period used for writing the information on the recording medium. The tracking error signal varies less than 10 % when the focal spot is defocused by one focal depth.

EXAMPLE II

The substrate of the recording medium is again made of polycarbonate (PC) having a refractive index of 1.58 at the design wavelength of 670 nm. The stack has the same order of layers as shown in Figure 1. Interference layer 5 is a 95 nm thick layer of 80% ZnS and 20% SiO_2 having a refractive index of 2.13. Recording layer 3 is a 25 nm thick layer of a $GeSb_2Te_4$ phase-change material having a refractive index of 4.26 - i 1.69 when in the amorphous state and 4.44 - i 3.08 when in the crystalline state. Interference layer 6 is a 35 nm thick layer of the same material as interference layer 5. Reflective layer 7 is a 100 nm thick layer of an aluminium alloy having a refractive index of 1.98 - i 7.81. The depth of grooves 9 is 35 nm, the width of the grooves is 550 nm and the pitch of the grooves is 740 nm.

The information is written in the grooves in the form of amorphous marks in a crystalline surroundings. The intensity reflection of stack 4 in a region of the recording layer in the amorphous state is equal to 0.05. The intensity reflection of stack 4 in a region in the crystalline state is equal to 0.16. The ratio of the amorphous reflection over the crystalline reflection is thus 0.31. Both regions are without grooves.

Radiation reflected from a region on track and in the crystalline state 'a' in Figure 2, is advanced in phase by 1.04 radian compared to radiation reflected from a region in between tracks and also in the crystalline state. Radiation reflected from a region on track and in the amorphous state 'c' in Figure 2, is advanced in phase by 0.7 radian compared to radiation reflected from a region on track and in the crystalline state, 'a' in Figure 2.

The push-pull tracking error signal has a measured maximum value of more than 85% of the value obtained for a medium having a groove depth optimized for a maximum push-pull signal. The phase-detection tracking error signal has a value of 0.72 clock periods at a radial tracking deviation of 0.1 μm. The tracking error signal varies less than 25 % when the focal spot is defocused by one focal depth.

Although the above examples of recording media according to the invention relate to media in which amorphous marks are written in crystalline surroundings, the invention can be applied equally well to media in which crystalline marks are written in amorphous surroundings. The invention is not limited to recording media in which the information is written in the grooves; the invention can also be applied to media in which the information is written on the lands in between the grooves. Stack 4 may have various forms. A further reflective layer may be arranged between substrate 2 and interference layer 5 of stack 4 as shown in Figure 1. Alternatively, a further interference layer and reflection layer may be interposed between the stack and the substrate. The stack may also comprise only layers 3, 4 and 5, which stack is very suitable for write-once media. The material of the recording layer may be a phase-change material, a dye, or any other material suitable for optically writing information in.

SCANNING DEVICE

Figure 3 shows an optical scanning device suitable for writing and reading information from the media according to the invention. The figure shows a part of record carrier 1 comprising embossed information in the form of pits and bumps. The information layer is scanned through substrate 2. The record carrier may comprise more than one information layer, arranged one above the other.

The apparatus comprises a radiation source 12, for instance a semiconductor laser, emitting a radiation beam 13. The radiation beam is focussed on information layer 3 by an objective system 14, for sake of simplicity shown in the Figure as a single lens. Radiation reflected by the information layer is directed towards a detection system 15 via a beam-splitter. The beam-splitter may be a semi-transparent plate, a diffraction grating and may be polarization-dependent. The detection system converts the incident radiation into one or more electrical signals, which are fed into an electronic circuit 16 to derive an information signal S_i representing information read from the record carrier, and control signals. One of the control

signals is the radial tracking error signal S_r, representing the distance between the centre of the spot formed by the radiation beam on the information plane and the centre-line of the track being scanned. Another control signal is a focus error signal S_f, representing the distance between the focal point of the radiation beam and the information plane. The two error signals are fed into a servo circuit 17, which controls the position of the focal point of the radiation beam. In the Figure the focus control is realized by moving objective system 14 in the direction of its optical axis in response to the focus error signal, whereas the radial tracking is realized by moving the objective system in a direction transverse to the tracks in response to the radial tracking error. During writing, the intensity of the radiation source is modulated by the information to be recorded.

Figure 4 shows the layout of the detection system 15 and part of the associated electronic circuit 16 for deriving a radial tracking error signals from the detector signals. Figure 4A shows the circuit for deriving a radial tracking error signal according to the push-pull method. The detection system 15 comprises a quadrant detector having four radiation-sensitive detection elements A, B, C and D. The detector signals from detector elements A and B are added and amplified in an amplifier 18. Likewise, the detector signals from detector elements C and D are added and amplified by an amplifier 19. The outputs of amplifiers 18 and 19 are connected to a differential amplifier 20, forming the difference of the two input signals. The output signal of differential amplifier 20 is the push-pull radial tracking error signal S_r(PP). This error signal is very suitable for controlling the radial tracking servo in parts of the recording medium having tracks without written marks.

Figure 4B shows the circuit for deriving a radial error signal according to a high-frequency phase-detection method. The detector signals from elements A and C of detection system 15 are added and amplified in amplifier 21. The output of amplifier 20 is fed into a slicer 22. The slicer detects level-crossings of the input signal with a detection level, thereby digitizing the input signal. The detector signals of elements B and D of detection system 20 are added and amplified in an amplifier 23, the output of which is connected to an input of a slicer 24. The output signals of amplifier 21 and 23 may be shaped by equalizers to compensate for effects of the response of the optical system of the scanning device on the detector signals, before being fed into slicer 22 and 24 respectively. The digital output signals of slicers 22 and 24 are fed into a phase comparator 25, which produces an output signal dependent on the phase between pulses in the two inputs of the comparator. The output signal of comparator 25 is low-pass filtered by filter 26. The output signal S_r of filter 26 is the radial tracking error signal derived according to the diagonal time-difference (DTD) method, which a

particular embodiment of the phase-detection method. This error signal is very suitable for controlling the radial tracking servo in parts of the recording medium comprising written marks.

The written tracks on a recording medium according to the invention can also be followed using a radial tracking error signal derived according to other high-frequency phase-detection methods, such as the analog version of the method shown in Figure 4B, or the analog or digital version of the phase-detection method known from inter alia United States patent no. US 4 785 441.

CLAIMS:

1. An optical recording medium for writing and reading information by means of a radiation beam having a predetermined wavelength and a predetermined numerical aperture, comprising a recording layer, the recording layer being changed from a first to a second state upon irradiation by a radiation beam, the recorded information being represented by written marks in the second state in a region in the first state, the marks being arranged in tracks comprising a guide groove having a width and a depth, a first optical phase difference existing on reflection from a region on track in the first state and from a region on track in the second state, the first optical phase difference enhancing an optical phase difference between a region in between tracks in the first state and a region on track in the first state, characterized in that the width of the guide groove is in the range from 0.3 to 0.6 times the wavelength over the numerical aperture, the depth of the guide groove is in the range from 1/24 to 1/7 times the wavelength over a refractive index met by the radiation beam, and the first optical phase difference is in the range from 0.4 to 2.0 radian.

2. Optical record carrier according to Claim 1, wherein the width and depth of the guide groove comply with

$$8.33\, NA\, D / n + 121\, NA / \lambda - 400\, NA\ \ \Phi / \lambda < W,$$

where NA is the numerical aperture and λ the wavelength in nanometres of the radiation beam, Φ the first optical phase difference in radians, n the refractive index, D the depth in units of λ / n and W the width in units of λ / NA.

3. Optical recording medium according to Claim 1, wherein a ratio of an intensity reflection of a region on track in the second state and of a region on track in the first state is larger than 0.15.

4. Optical recording medium according to Claim 1, wherein a ratio of an intensity reflection of a region on track in the first state and of a region on track in the second state is larger than 0.15.

5. Optical recording medium according to Claim 4, wherein the intensity reflection of a region on track in the first state is larger than 0.15.

6. Optical recording medium according to Claim 5, wherein the intensity reflection of a region on track in the second state is larger than 0.15.

7. Optical recording medium according to Claim 1, wherein the depth of the guide groove is in the range from 1/12 to 1/7 times the wavelength over the refractive index.

8. Optical recording medium according to Claim 1, wherein the recording layer comprises a material having an imaginary part of the refractive index in the first state larger than 3.4.

9. Optical recording medium according to Claim 1, wherein the recording layer comprises a phase-change material.

10. Optical recording medium according to Claim 9, wherein the second state is amorphous.

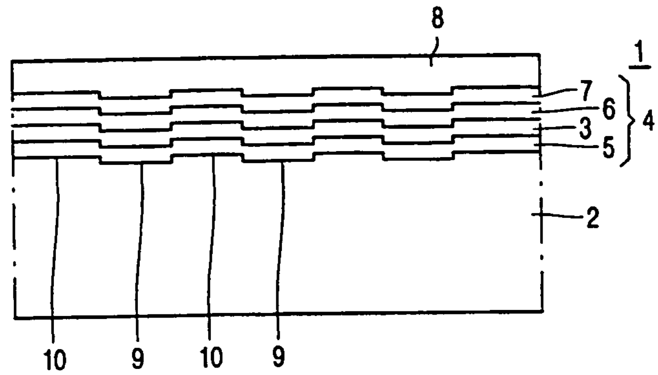

FIG. 1

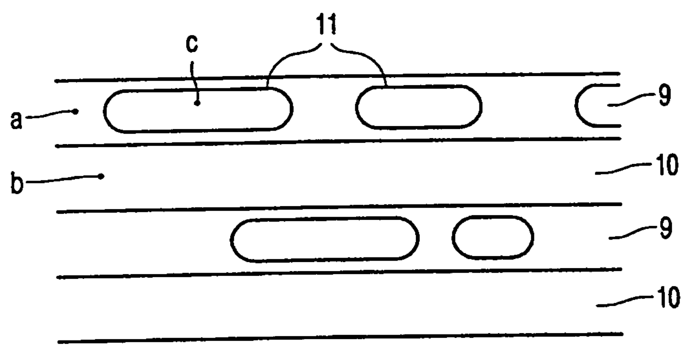

FIG. 2

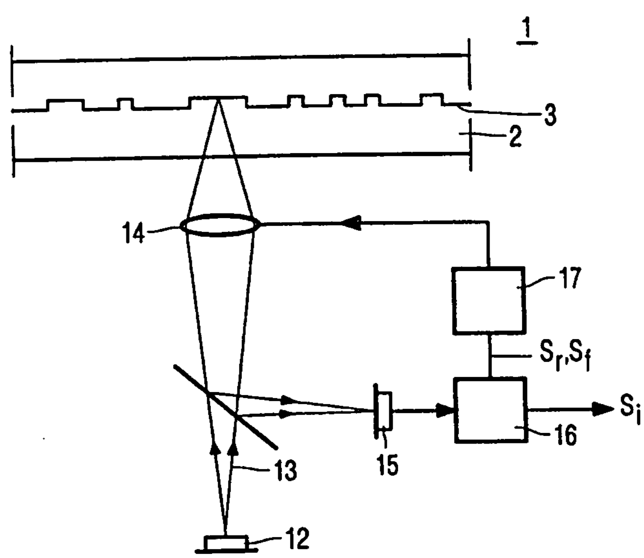

FIG. 3

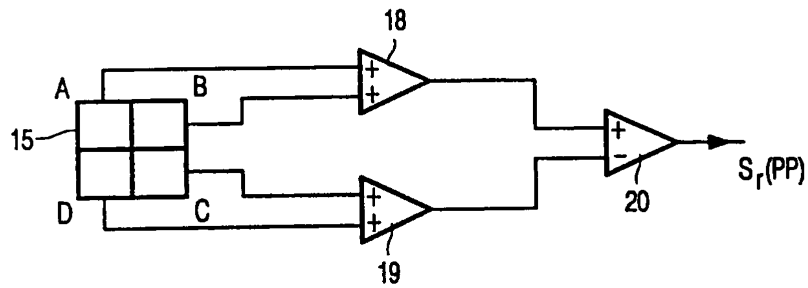

FIG. 4A

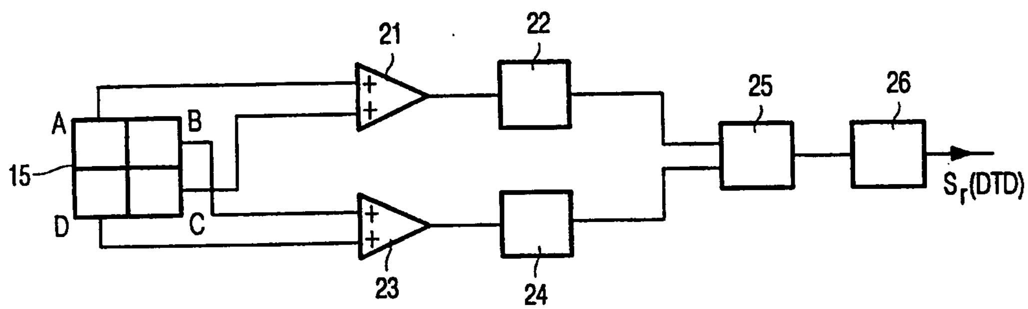

FIG. 4B